Island conservation in north-west Mexico: a conservation model integrating research, education and exotic mammal eradication

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Dedication This paper is dedicated to Jesús Ramírez, whose work marked the beginning of island conservation in Mexico.

Abstract The 250+ islands of north-west Mexico support 50 taxa (species and subspecies) of breeding seabirds and over 180 taxa of endemic terrestrial vertebrates. Isolation and aridity have historically protected these islands from many human perturbations and consequently their biotas are relatively intact. However, invasive alien mammals have been introduced to at least 44 islands and are responsible for the ecological extinction of 22 endemic vertebrate species and subspecies, and the local extinction of one or more seabird taxa on 10 islands. The Island Conservation and Ecology Group, the National Autonomous University of Mexico, Center for Biological Investigations, and National Protected Areas Department collaborated with local people and other NGOs to remove one or more introduced mammals from 23 islands and will soon complete eradication on one more. This work has protected habitat for 27 seabird taxa, seven of which are endemic to the region, and 38 endemic taxa of terrestrial vertebrates. Our regional, science-based, collaborative approach to island conservation has eradicated invasive alien mammals from most islands under 40 km^2 in this biologically important region. We are building on this experience to conduct eradications on larger, more-difficult islands.

Keywords endemic species; extinction; extirpation; invasive alien; Baja California; Gulf of California; introduced species.

La conservación de islas en el noroeste de México: un modelo de conservación que integra la investigación, educación y erradicación de mamíferos exóticos

Dedicatoria: Este artículo está dedicado a Jesús Ramírez, cuyo trabajo marcó el inicio de la conservación de islas en México.

Resumen Las más de 250 islas del noroeste de México contienen 50 taxones (especies y subespecies) de aves marinas en reproducción y más de 180 especies y subespecies de vertebrados terrestres endémicos. A lo largo de la historia el aislamiento y la aridez han protegido a estas islas de las perturbaciones y consecuentemente la biota se ha mantenido relativamente intacta. Sin embargo, mamíferos ajenos a islas han sido introducidos a por lo menos 44 islas y son responsables de la extinción ecológica de 22 especies y subespecies de vertebrados endémicos y de la extinción regional en diez islas de uno o más taxones de aves marinas. El Grupo de Ecología y Conservación de Islas, la Universidad Nacional Autónoma de México, el Centro de Investigaciones Biológicas y el Departamento de Áreas Nacionales Protegidas han colaborado con la gente de la región y con otras agencias no gubernamentales para remover una o más especies de mamíferos exóticos de 23 islas y muy pronto de otra más. Este trabajo ha protegido el hábitat de 27 especies y subespecies de aves marinas, siete de las cuales son endémicas de la región, y de 38 especies y subespecies endémicas de vertebrados terrestres. Nuestro enfoque hacia la conservación de islas es regional y con base en investigación científica y la colaboración, y ha removido los mamíferos exóticos de la mayoría de las islas menores a 40 km^2 en esta importante región biológica. Esta experiencia nos permitirá llevar a cabo erradicaciones en islas más grandes y difíciles.

INTRODUCTION

Many island ecosystems lack native terrestrial mammals (Carlquist 1974). This unique evolutionary history makes island ecosystems particularly vulnerable to the impacts of invasive alien mammals because: (1) native island species generally have poor behavioural, physical, and life history defences against mammalian herbivory and predation (Mooney and Drake 1986; Stone *et al.* 1994; Bowen and Van Vuren 1997), and (2) island ecosystems typically

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lack native predators that can regulate invading mammal populations. Consequently, the introduction of alien mammals to island ecosystems is one of the greatest causes of recorded global extinctions (Elton 1958; King 1985; Atkinson 1989; Diamond 1989; Groombridge *et al.* 1992).

The more than 250 islands in north-west Mexico are known for their high biodiversity, endemism, important seabird colonies, and relatively-low levels of human disturbance (Case and Cody 1983; Everett and Anderson 1991; Ceballos *et al*. 1998; Alvarez-Castaneda and Patton 1999; Grismer 1999; Donlan *et al*. 2000). Historically, these islands were protected from most direct human perturbations by aridity, isolation, and low human population densities on the adjacent mainland (Tershy *et al.* 1997). Today, most of the islands are government owned and legally protected from many forms of land conversion (Carabias-Lillo *et al.* 2000). However, alien mammals were introduced to many of these islands starting in the late 1800s and early 1900s (Jehl and Parkes 1982; Jehl and Everett 1985; Brattstrom 1990; Martinez-Gomez and Curry 1996; McChesney and Tershy 1998). Alien mammal introductions continue to take place and this threat is exacerbated by dramatic increases in human use of the islands over the last 30 years (Velarde and Anderson 1994; Tershy *et al.* 1999).

To prevent extinctions and protect natural ecological and evolutionary processes, we have been studying and removing invasive alien mammals from islands in north-west Mexico since 1994. In this paper we review the distribution and impacts of introduced mammals on these islands, and summarise our alien mammal eradication projects. We discuss our regional conservation model that integrates applied research, environmental education, and invasive alien mammal eradication.

METHODS

Approach

We formed a bi-national, non-profit conservation group, the Island Conservation and Ecology Group, to conduct science-driven conservation and applied research on the islands of north-west Mexico. In order to help prioritise our efforts, we developed a conservation biodiversity database. This public database, available via the internet, serves as a central data location, holding referenced data on the distribution and abundance of both native and alien species across multiple taxa, as well endemism levels, island geography data, and human use data (http://www.islandconservation.org, Donlan *et al*. 2000). This database was used to help prioritise islands for alien mammal eradications, based on their biodiversity, the potential impacts of alien mammals, and the political and technical feasibility of the eradication. Once islands were identified for eradication, we implemented local environmental education programmes to gain community support for eradications and worked collaboratively with local and national management agencies on each island (Donlan and Keitt 1999). Our Mexico branch developed the environmental education programmes, which included on-island presentations; school field trips to encourage appreciation of native biodiversity; island conservation education materials such as bumper stickers, videos, and books; and actively involving island residents in aspects of selected projects.

For actual eradications, we trained local biologists to remove introduced rodents from islands and recruited and trained local hunters and trappers for larger alien mammal eradications (i.e., feral cats, goats, and rabbits). Our eradication efforts began on small islands (<3 km^2), that were used by only a limited number of people; hence, both eradication and gaining complete community support were relatively easy and inexpensive. With experience and success on small islands, our hunting/trapping team grew in numbers and experience, and our relationships with agency staff and funders developed. This enabled us to work on progressively larger and more politically-complex islands, and to work on multiple islands simultaneously. In conjunction with the eradication programme, we developed a research programme designed to study the impact and recovery of island ecosystems from exotic mammals (Keitt 1998; Donlan 2000; Keitt *et al*. 2000a, 2000b; Donlan *et al.* 2002; Roemer *et al*. 2002).

Distribution and impacts of alien mammals

To summarise the distribution and impacts of alien mammals on the islands of north-west Mexico we relied on published and unpublished literature including museum specimens, historical records, personal communications from researchers and island residents, and our own field notes. A brief visit to an island was usually sufficient to confirm the presence or absence of larger alien mammals. Also, local island users or other researchers could reliably report on the presence or absence of rabbits, cats, goats, sheep, pigs, or donkeys. Determining the status of introduced rodents on the islands proved more difficult; most island users, including researchers, could not reliably distinguish between native and alien rodents. We visited islands that were suspected of having introduced rodents, and live-trapped (most islands have native rodents) for several nights (2 – 5 nights) to confirm their presence. Not all islands have been surveyed for introduced rodents and a systematic survey would likely result in additional records.

To measure some of the impacts of alien mammals on these island ecosystems, we identified islands where native vertebrate species and subspecies had been reduced to such low numbers by alien mammals that they were ecologically extinct; that is, unlikely to perform a functional role in the island ecosystem (sensu Estes *et al.* 1989). We considered a taxon ecologically extinct if a competent researcher was unable to detect its presence after several visits; the majority of these extinctions can be attributed to alien mammals (Jehl and Everett 1985; Mellink 1992;

Smith *et al*. 1993; Howell and Webb 1995; Alvarez-Castaneda and Cortes-Calva 1996; Alvarez-Castaneda and Patton 1999; Collins 1999; Donlan *et al.* 2000; Junak and Philbrick 2000). Thus, as we use it here, ecological extinction is synonymous with possible global extinction. We chose ecological extinction since global extinction is often difficult to confirm on these remote islands and, in the short term, the ecosystem impacts are synonymous (Estes *et al.* 1989). Our assessment concentrated on vertebrates, since they are the most studied and well-known group in the region (Howell and Webb 1995; Alvarez-Castaneda and Patton 1999; Grismer 1999). We combined data for species and subspecies since both taxa are evolutionally significant (Ryder 1986; Rojas 1992), and the distinction between them is often dependent on how well and how recently the taxonomy for a given group has been revised. Some seabirds were driven to local extinction on one island, but populations persisted on other islands (McChesney and Tershy 1998); we recorded these local extinctions separately. All data on the distribution and impact of alien mammals were compiled in the aforementioned database for planning and research, which is accessible to the public for planning and research (Donlan *et al*. 2000).

Alien mammal eradications

Black rats (*Rattus rattus*) were eradicated from four islands (San Roque Island and the three San Jorge Islands), and Norway rats (*R. norvegicus*) and house mice (*Mus musculus*) from Rasa Island (Table 1). A bait station approach using rodenticide was employed in all cases (sensu Taylor and Thomas 1993). The bait stations were placed evenly across islands on a 25 x 25m grid. Extra stations were added along the shoreline where rat densities tended to be highest. On the San Jorge Islands, three rodenticides were used in the eradications. Brodifacoum (50 ppm, Final® Blox™ Bell Laboratories) was used on the main island, diphacinone (50 ppm, Ditrac® Blox™ Bell Laboratories) on the east islet, and cholecalciferol (750 ppm, Quintox® Bell Laboratories) on the west islet. Brodifacoum and diphacinone bait were in 20g extruded cereal wax blocks. Cholecalciferol bait was in cereal pellet form and dispensed in 10g packages. Bait stations remained active for one year; details of the San Jorge eradication are discussed elsewhere (Donlan *et al*. in press). On San Roque Island, brodifacoum wax blocks were used in combination with 100 ppm bromethalin in a gel bait; stations remained active for one year (Donlan *et al*. 2000). In 1994, Norway rats and house mice were eradicated from Rasa Island by Jesús Ramírez (deceased) of the Instituto de Ecologia, using bait stations on a 25 m grid containing 50 ppm brodifacoum wax blocks. None of the authors were directly involved in the Rasa Island project.

Successful eradication of introduced cats, rabbits, goats, and sheep was accomplished through a combination of environmental education and hunting and/or trapping. Hunters tended to work simultaneously on several islands at any one time, moving opportunistically between the islands depending on the number of alien mammals that appeared to remain on the island and logistic factors such as weather, transportation, and the availability of rifles and ammunition.

On Natividad Island, community education programmes resulted in live removal of sheep, goats, and dogs by island residents (Keitt 1998; Donlan and Keitt 1999). With active eradications, rabbits and cats were hunted both day and night (often with the aid of trained dogs), and trapped with Victor # 1½ padded leg-hold traps. Cat hunting and trapping techniques are described in detail by Wood *et al.* (2002). Rabbits were hunted during the day and night with 12 gauge shotguns and .22 calibre rifles. Dogs, Jack Russell Terriers, were used to hunt rabbits primarily during the day. Typically, a hunter would follow a single dog from a distance of up to 200m, often simply watching or listening to the dog from an elevated vantage point. Only when the dog's behaviour suggested it had located a rabbit, would the hunter investigate the area in detail. Jack Russell Terriers were often able to locate hidden rabbits and crawl into holes to reach them. However, hunters usually set traps outside occupied rabbit holes, so they could be more certain they had captured the occupant.

Goats were removed by hunting during the day with .22 and .222 calibre rifles. Dogs were not used for goat hunting. All hunting and trapping were done on foot, but small boats were sometimes used to move hunters/trappers to different parts of the islands.

After each island was thought to be free of the target species due to the absence of sign, at least two subsequent visits were made at three to eight month intervals to check for new sign. Only if no fresh sign was found on these subsequent visits, was an eradication considered to have been successful.

RESULTS

Distribution and impact of introduced mammals

In 1994 alien mammals occurred on at least 44 islands in north-west Mexico and are implicated in causing the ecological extinction of 22 endemic species and subspecies of vertebrates, as well as the local extinction of one or more seabird species from at least 10 islands (Fig. 1). Of the 22 ecological extinctions, there is substantial evidence that some have suffered global extinction (Mellink 1992; Smith *et al*. 1993; Howell and Webb 1995; Alvarez-Castaneda and Patton 1999).

Introduced mammal eradications

In collaboration with The Instituto de Ecologia at the Universidad Nacional Autonoma de Mexico, Centro de Investigaciones Biologicas del Noroeste, the national and regional offices of Areas Naturales Protegidas, and local people and community organisations, we have eradicated

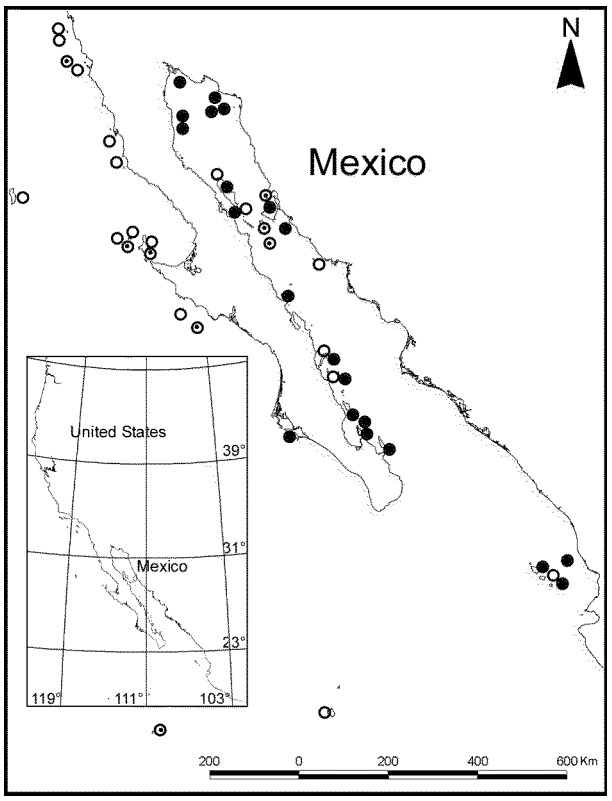

Fig. 1 North-west Mexico islands with alien invasive mammals in 1994 that did not suffer ecological extinctions (black circles), that suffered one or more ecological extinctions of endemic taxa (circles with black dot), or suffered the local extinction of one or more seabird species (white circles).

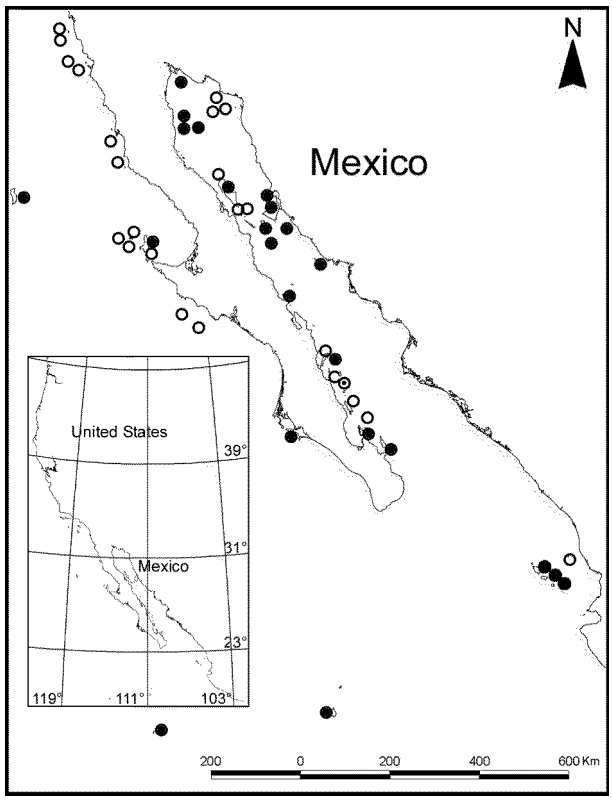

Fig. 2 The eradication of one or more invasive alien mammals from 23 islands in north-west Mexico. Islands from which one or more alien invasive mammals have been removed (white circles), where eradication is nearly complete (circle with black dot), and where they remain (black circles).

one or more introduced mammals from 23 islands (Fig. 2, Table 1). Eradication on one additional island is near completion (Fig. 2, Table 1). This work has protected habitat for 38 endemic taxa of terrestrial vertebrates, and 27 breeding seabird taxa, seven of which are endemic to north-western Mexico (Table 1). The estimated cost of these conservation actions, excluding the work on Rasa Island, was approximately USD750,000.

The first eradication was conducted in autumn 1994 and the most recent completed eradication was finished in winter 2000. From the start of hunting and trapping to when the last animal was captured lasted anywhere from 24 hours (14 cats on <1 km^2 San Geronimo Island) to over nine months on San Benito Oeste (3.5 km^2), where approximately 400 rabbits were removed.

DISCUSSION

Islands are critical for the conservation of global biodiversity, and the islands of north-west Mexico are no exception (Velarde and Anderson 1994; Ceballos *et al*. 1998; Donlan *et al*. 2000). As in other parts of the world, the main threats to these island ecosystems are the predation, competition, and habitat alteration caused by invasive alien species (Mellink 1992; Smith *et al*. 1993; Velarde and Anderson 1994; Alvarez-Castaneda and Cortes-Calva 1996; Keitt 1998; Donlan 2000; Donlan *et al*. 2000). Alien mammals appear to be responsible for more than 90% of the ecological extinctions of endemic vertebrates, and numerous local extinctions of seabirds (Donlan *et al*. unpub. data; McChesney and Tershy 1998). Fortunately, due to techniques developed by New Zealand conservation practitioners (Towns *et al*. 1990), alien mammals can be removed from islands in this region as evidenced by the successful projects described above.

These conservation successes were made possible by the model that we developed: an integrated bi-national team that coordinates and facilitates all aspects of island conservation (applied research, prioritisation, fundraising, public support through community education, alien mammal eradication, and protection against new introductions). Our research programme has provided evidence for population and ecosystem-level impacts of invasive alien species and insight on the recovery of systems after mammal eradication (Keitt 1998; Donlan 2000; Donlan *et al*. 2002; Roemer *et al*. 2002). Research at the regional level, particularly the development of the conservation database, has provided a biogeographical framework to prioritise our conservation efforts, as well as providing a conservation tool to Mexican government agencies (Carabias-Lillo *et al*. 2000; Donlan *et al*. 2000). A bi-national framework allows access to U.S funding opportunities, through our

Table 1 Islands from which alien invasive mammals have been removed and number of native taxa protected.

Islands (north to nouth)	Area (km^2)[1]	Aliens Removed	Breeding Seabirds[2]	Endemic species and subspecies[3]		
				Reptiles	Landbirds	Mammals
Pacific						
Coronado Norte[4]	< 1	Cats	11 (3[9])	2	2	1
Coronado Sur	1.8	Goats	7	4	2	1
Todos Santos Norte	< 1	Cats, Rabbits	5 (1[9])			2 (1[9])
Todos Santos Sur	1.0	Cats, Rabbits	6 (1[9])	2	1[9]	2 (1[9])
San Martin	3.2	Cats	6 (3[9])	3		2 (1[9])
San Geronimo	< 1	Cats	5			1
San Benito Oeste[5]	3.5	Rabbits, Goats	10	1	3 (1[9])	
San Benito Medio	< 1	Rabbits	10	1	2 (1[9])	
San Benito Este	1.1	Rabbits	12	1	3 (1[9])	
Natividad[6]	7.2	Cats, Goats, Sheep	6 (1[9])			1
San Roque	< 1	Cats, Black rats	6 (1[9])			1 (1[9])
Asuncion	< 1	Cats	7 (4[9])			
Gulf of California						
San Jorge East	< 1	Black rats	8 (2[9])			
San Jorge Middle	< 1	Black rats	8 (2[9])			
San Jorge West	< 1	Black rats	8 (2[9])			
Mejia	3.0	Cats	3	2		2 (2[9])
Estanque	< 1	Cats	1	1		
Rasa[7]	< 1	Norway rats, Mice	4			
Coronados	8.5	Cats	1	1		3 (2[9])
Monserrate	19.4	Cats	2	2		2 (2[9])
Catalina (incomplete)	43.1	Cats	2	8		1
San Francisco	2.6	Cats, Goats	1	2		2
Partida South	20.0	Cats	0	3		1
Isabela[8]	1.0	Cats	10			
TOTAL		32 removals	139 (27) 7[2]	33 (27)[3]	13 (6)[3]	22 (19)[3]

[1] Areas are estimates based on literature.
[2] 139 seabird populations (27 seabird species and subspecies), seven endemic to north-west Mexico.
[3] Number of endemic populations (number of endemic species and subspecies), some taxa occur on more than one island.
[4] Feral donkeys present.
[5] Donkeys are corralled and fed imported pelletised food.
[6] All feral dogs, and most pet dogs, have been removed, <10 pet dogs remain in the fishing village and residents have agreed to remove them by 2003; the ground squirrel *Ammospermophilus leucurus* was introduced from the adjacent mainland and is established.
[7] Project conducted by Jesús Ramírez (deceased) of the Instituto de Ecologia, Universidad Nacional Autónoma de México without participation of Island Conservation and Ecology Group.
[8] Island Conservation and Ecology Group assisted Cristina Rodríguez of Instituto de Ecologia, Universidad Nacional Autónoma de México; Norway rats still present.
[9] Possible extinctions (extirpations for seabirds) (e.g., 3 (2[9]) = three endemics, two of which may be extinct).

U.S office; these conservation dollars can be directed toward projects in Mexico where funding opportunities are less. Our Mexican branch facilitates efficient and successful interactions with Mexican government agencies, as well as develops local capacity. Local support of island users through community involvement and education in conjunction with eradications is critical, particularly with respect to the prevention of new introductions (Keitt 1998; Donlan and Keitt 1999).

We believe that this regional island conservation model is more effective than a series of single-island efforts for three reasons. First, the process of planning, obtaining public support, fundraising, and staff training does not have to be repeated for each island, and the knowledge accumulated during the course of each project is not lost when each island project is completed. Second, economies of scale enable an expert national or regional team to train and employ individuals with complimentary expertise who can, when appropriate, train or supervise a team of talented locals on each island or island group. Third, a regional perspective facilitates the selection of project islands based on an objective evaluation of team capacity, the available funding, the biological importance of the island, and the political and technical difficulties inherent in project.

Using this approach, in collaboration with our colleagues, we have removed alien mammals from most of the islands in north-west Mexico smaller than 40 km^2. With the experience and infrastructure developed on these islands, and the help of experts in New Zealand and other parts of the world, we hope to facilitate the removal of alien mammals from most of the remaining islands in north-west Mexico.

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